

# Sustainable management of wildlife habitat and risk of extinction

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## Abstract

Whether land management planning provides for sufficient habitat to sustain viable populations of indigenous wildlife is one of the greatest challenges confronting resource managers. Analyses of the effects of land management on natural resources often rely on qualitative assessments that focus on single species to reflect the risk of wildlife extinction across a planning area. We propose a conceptual framework for sustainable management of wildlife habitat that explicitly acknowledges the greater risk of an extinction event when considering the viability of multiple species, e.g., an indigenous vertebrate fauna. This concept is based on the principle that the likelihood of at least one event (i.e., species extinction) is the joint probability of the extinction probabilities of individual species, assuming independence among species' responses to disturbance. We present an ecological rationale to support the view that, at a spatial scale of  $10^4$ – $10^6$  ha (i.e., planning area) and a temporal scale of  $10^2$  years (i.e., planning horizon), wildlife species operating at varying ecological scales respond relatively independently to disturbances typically associated with land management. We use a hypothetical scenario of a wildlife viability assessment and Monte Carlo simulation to demonstrate that the probability of 'any extinction' is consistently higher than the probability of the 'single most likely' extinction, and that the difference between these values increases as more disturbance-sensitive species (i.e., species at risk) are analyzed. We conclude that risk assessments that rely upon the most sensitive single species may substantially underestimate the risk of wildlife extinction across a planning area. Furthermore, the selection of a planning alternative based on relative threat of local extinction of wildlife populations can vary depending on which paradigm is used to estimate risk to viability across the planning area.

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## 1. Introduction

Achieving sustainable use of natural resources has become a global issue, reconciliation of which is fundamental to preserving biological diversity (Mace and Lande, 1991; Lindenmayer, 1996; Keith, 1998; Szaro et al., 2000; Rosenzweig, 2003). Land-use changes, especially habitat loss, are implicated as a causal factor in

declines of 83% and 89% of all threatened birds and mammals, respectively (Pereira et al., 2004). Furthermore, the decisions that policy makers face regarding management of natural resources have become increasingly complex (Murphy and Noon, 1991; Thomas, 1991; Forest Ecosystem Management Assessment Team[FEMAT], 1993; Hanley, 1994; Everest et al., 1997; Rauscher, 1999; Szaro et al., 2000) with many new challenges, not the least of which was adopting ecosystem management as the philosophical paradigm (Szaro et al., 1998; Rauscher, 1999). Wildlife viability continues to rank high among land management issues

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on public (Jerry, 1984; Thomas, 1991; Possingham et al., 1993; Marcot and Murphy, 1996; Iverson and Rene, 1997) and industrial (Smith and Pashley, 1994; Bullock and Wall, 1995; Lindenmayer and Possingham, 1996) lands because wildlife species are valued by many segments of society (Cotton and Mighetto, 1998; Leopold, 1933; Naess, 1986), and because the persistence of wildlife at 'ecologically effective' densities (*sensu* Soulé et al., 2003: p. 1239) is a crucial component of healthy ecosystems (Gilbert, 1980; Odum, 1969; Petchey, 2000; Pimm, 1991; Pyare and Berger, 2003; Soulé et al., 2003).

Broad-scale land-use planning usually involves development of an array of alternative management scenarios for future use of large areas ( $10^4$ – $10^6$  ha) during long time periods ( $\geq 10^2$  years). Typically, these management alternatives span a range of development scenarios from 'No Action' to a strong emphasis on provision of goods and services. Alternatives vary in amount and distribution of land uses or values such as timber harvest, mining, grazing, recreation and tourism, wilderness, and road access over space and time (Forest Ecosystem Management Assessment Team, 1993; Lindenmayer and Possingham, 1996; Iverson and Rene, 1997; Shaw, 1999). The potential impacts of alternative future scenarios on natural resource values, such as the viability of wildlife populations, are assessed and this information is used to select a preferred land management plan (Forest Ecosystem Management Assessment Team, 1993; Lindenmayer and Possingham, 1996; Shaw, 1999; Possingham et al., 2002).

Substantial effort has been directed by federal (Forest Ecosystem Management Assessment Team, 1993; USDA Forest Service, 1997) and state (Washington State Department of Natural Resources, 1997; Oregon Department of Forestry, 1995, 2001) agencies and industry (Loehle et al., 2002) in North America and internationally (Lindenmayer and Possingham, 1996) toward developing land management or habitat conservation plans. Still, planners struggle with credibly projecting impacts of land management on wildlife viability (Possingham et al., 1993; Ruggiero et al., 1994; Todd and Burgman, 1998; Shaw, 1999; Ruggiero and McKelvey, 1999). Many challenges are directly attributable to the dearth of relevant empirical data required to conduct rigorous analyses (Possingham et al., 1993; Ruggiero et al., 1994; Coulson et al., 2001; McCarthy et al., 2001). Moreover, the complexity of nature severely complicates conservation assessments of ecological communities and it becomes effectively impossible to accurately project impacts of an array of alternative management scenarios on wildlife populations (Beissinger and Westphal, 1998).

Several approaches to evaluating effects of land use on natural resources have been proposed (Landres et al., 1988; Loehle et al., 2002; Manley et al., 2004; Simberloff, 1998; Verner, 1984). Some schemes reputedly

serve as a barometer of ecosystem health (Simberloff, 1998) or are indicators of biodiversity (Lawler et al., 2003; Lawton et al., 1998), whereas others assess the effects of management on the persistence of threatened species (Possingham et al., 2002). One approach is to predict responses of a representative subset of vulnerable species that are disturbance-sensitive and at risk of local extirpation (Shaw, 1999). There have been multiple variations of this theme (Forest Ecosystem Management Assessment Team, 1993; Quigley et al., 1997), but typically species at risk comprise a limited (4–8) number of species that likely respond uniquely to the full range of land management alternatives under consideration. Each vulnerable species is assumed to respond to alternative plans in a manner that reflects the response of a large number of species, i.e., other members of the ecological community. Ostensibly, the set of species at risk represent a wide enough range of taxa and ecological life styles that the breadth of possible responses to management alternatives under consideration is captured in the responses of vulnerable species, but with little or no correlation among their responses to a particular plan alternative. This approach has been challenged (Landres et al., 1988; Mannan et al., 1984; Niemi et al., 1997; Simberloff, 1998; Szaro, 1986; Verner, 1984) because of difficulty in identifying species that satisfy these criteria.

Nonetheless, land managers are accountable for sustainable management of natural resources. On public forestlands, the National Forest Management Act (36 CFR 219.19, USDA Forest Service, 1982:43048) requires that the USDA Forest Service manages national forests in a manner that provides sufficient habitat to sustain "all" indigenous wildlife across a planning area (Jerry, 1984; Marcot and Murphy, 1996; Thomas, 1991; Iverson and Rene, 1997). An intriguing corollary, and the fundamental thesis of this paper, is that managers must consider impacts of land-use plans upon the probability of losing "any" indigenous wildlife (Jerry, 1984; Marcot and Murphy, 1996). In the United States, private landowners with multiple threatened or endangered species face similar constraints under the Endangered Species Act (Bullock and Wall, 1995).

The purpose of our paper is to demonstrate that using the most vulnerable species to assess impacts of land use on biological diversity likely underestimates the probability of extinction of wildlife species across the planning area. Specific objectives are to review concepts and procedures of a common land-use planning paradigm on public forests; to describe an alternative paradigm that explicitly considers the risk of extinction as a function of number of vulnerable species in wildlife communities; to illustrate with a hypothetical example the extent of disparity that can exist in extinction probabilities between risk assessments that focus on the 'most' vulnerable species and risk assessments that

estimate the probability of ‘any’ extinction of multiple vulnerable species; to demonstrate the effect of number of species at risk on that disparity; and to demonstrate the implications of this disparity between paradigms on land-use planning.

## 2. Methods

The National Environmental Policy Act (NEPA) of 1969 established policy to prevent human-caused damage to the biosphere, from which precipitated a framework and procedures for land-use planning. An integral component of the NEPA process is developing land-management alternatives, which typically are designed around a particular ‘theme’ that emphasizes an issue or group of issues (e.g., recreation opportunities; USDA Forest Service, 1997). Number and range of alternatives depend on the diversity of issues and their compatibility. NEPA requires that an analysis of environmental consequences be conducted, including the effect of implementing each plan alternative on a broad spectrum of natural resources. Because it is impractical to assess the impact of implementing each plan alternative on all indigenous wildlife species, a group of species of management concern are selected to reflect the risk of wildlife extinction across the planning area (Shaw, 1999).

Once a species list is compiled, a probability of extinction is estimated for each taxon under each alternative. These predictions are based upon a population viability analysis if relevant information is available (Akçakaya, 1992, 2000; Boyce, 1992; Brook et al., 2000; Ruggiero et al., 1994; Ruggiero and McKelvey, 1999); or, expert panels are convened to obtain professional opinions about impacts to each taxon of implementing each alternative. Often, the projected effects of each alternative on habitat or other crucial resources form the basis of an ecological rationale that underpins the panel’s assessment. This process generates a set of estimates of the probability of persistence for each species under each plan alternative (Forest Ecosystem Management Assessment Team, 1993; Shaw, 1999). To determine the influence of alternatives upon wildlife viability, planners often examine the marginal risk (i.e., extinction probabilities of individual species) of species at risk under each alternative and focus attention on the taxon with the highest projected risk of extinction with implementation of the alternative. This species with its probability of extinction is used to reflect the risk to wildlife population viability across the planning area for the alternative under consideration (Shaw, 1999). This ‘most sensitive’ species approach is not the only tool used by planners to assess the impacts of alternatives upon wildlife viability. However, it shares some implicit and limiting assumptions (see below) with many of the

less quantitative alternative procedures (Todd and Burgman, 1998).

We propose an approach for assessing risk to wildlife viability that explicitly considers the risk of “any” extinction among species at risk in the planning area. This probability easily can be calculated as the “likelihood of at least one success” (Snedecor and Cochran, 1980: p. 115), or the probability that “any” species will become extirpated. In statistical terms, if  $n$  species at risk each have an independent probability of going extinct ( $P$ ) under a management alternative, then the probability that at least one, or any, of these species at risk goes extinct is given by the binomial theorem (Snedecor and Cochran, 1980: p. 115). Thus, the probability of extinction following implementation of an alternative is the joint probability of marginal probabilities and calculated according to the following equation:

$$P(\text{Any}) = 1 - \prod_{i=1}^j [1 - P_{\text{ext}}(\text{Species})_i], \quad (1)$$

where  $P(\text{Any})$  equals the probability that “any” of the  $j$  species at risk will become extinct locally and  $P_{\text{ext}}(\text{Species})_i$  is the probability that the  $i$ th species will become extinct locally.

To illustrate this approach, we created a scenario and used Eq. (1) to calculate the probability of ‘at least one extinction’ among four hypothetical species at risk and their corresponding marginal probabilities for each of five management alternatives, similar to procedures used in planning for the Northwest Forest Plan (Forest Ecosystem Management Assessment Team, 1993), Interior Columbia Basin Ecosystem Management Project (ICBEMP; Quigley et al., 1997) and Tongass Land Management Plan (TLMP; USDA Forest Service, 1997). In addition, we compared the order ranking of plan alternatives (Lindenmayer and Possingham, 1996; Possingham et al., 2002) based on relative risk of extinction from FEMAT, TLMP and ICBEMP using the current paradigm of selecting the single most vulnerable species versus the probability of any extinction.

We used a simple Monte Carlo simulation to obtain a systematic assessment of how the probability of ‘any’ extinction and the probability of the ‘single most likely’ extinction differ as a function of number of species analyzed. We developed simple scenarios in a spreadsheet that were based on 2, 4, 6, 8 or 10 species at risk. In these scenarios, we used a random number generator to create 50 replicate sets of 2, 4, 6, 8 or 10 random numbers between 0.05 and 0.45. These values were assumed to represent the risk of extinction to independent species in response to a management alternative. For each set of values we calculated both the probability of ‘any’ of the species from the set going extinct (Eq. (1)) and the ‘single greatest’ extinction risk faced by any of the

species in the set. We then averaged these values for each method and number of species at risk.

### 3. Results and discussion

Clearly, when marginal probabilities (Table 1) are used to calculate the probability of “any” (at least one) extinction under each management alternative, the risk to wildlife viability is consistently and markedly higher than that obtained from selecting the most vulnerable species at risk (Table 2). Also, the management plan that poses the highest risk to the most vulnerable species may not necessarily represent the greatest threat to the wildlife community. Furthermore, the probability of ‘any’ extinction (and its disparity with the risk of the single most sensitive species) increases as number of vulnerable taxa under consideration increases (Fig. 1). However, the dearth of relevant information and difficulties of conducting multiple PVAs or interpreting results of expert opinion panels limit inferences regarding the extinction risk of implementing plan alternatives. Thus, to be useful it is essential to frame such analyses in terms of relative (rather than absolute) risk of extinction (Beissinger and Westphal, 1998), with a focus on added threats posed by future land management. One approach to consider is ranking land management alternatives based on their relative risk of extinction (Possingham et al., 2002). Still, there is value in acknowledging the magnitude of disparity between these two paradigms because using the most vulnerable species may mislead land managers to a false sense of security regarding the viability of wildlife communities.

Consider the hypothetical viability assessment we developed in Tables 1 and 2. Based on results of applying the binomial theorem, Alternative 1 has the best chance of preserving wildlife across the planning area, whereas Alternative 3 presents the highest risk to overall wildlife viability. It also is reasonable to conclude that the relative risk of wildlife extinction from implementing Alternative 3 is on an order of 3 times greater than that of implementing Alternative 1 (Table 2). However, because of the limitations of risk assessment panels (Todd and Burgman, 1998; Shaw, 1999), it is inappropriate to infer that there is an 86% chance of extinction from implementing Alternative 3 as compared to a 27% probability of extinction if ‘No Action’ was implemented.

Interestingly, extreme (i.e., emphasis of maintaining biological diversity versus emphasis of goods and services) alternatives may receive identical relative rankings using both the probability of ‘any’ extinction and the probability of the ‘single most likely’ extinction (e.g., TLMP; Table 3), whereas the relative ranking of plan alternatives with intermediate probabilities appear more sensitive to the approach selected to assess risk (Table 3). For the TLMP example, alternative 6 ranked second (behind the ‘No Action’ alternative) based on the single-most likely extinction, whereas it ranked fifth among scenarios according to the probability of ‘any’ extinction. Alternatives 3, 4, and 5, also had different rankings between analytical approaches. This difference among plan alternatives with intermediate rankings can be decisive for management planning where wildlife viability plays a prominent role in effects analyses and selection of a preferred alternative because rarely (if ever) are the ‘No Action’ or ‘maximize goods and services’ alternatives given serious consideration (Forest Ecosystem

Table 1  
Probabilities (%) of two consequences for each wildlife species and each land management plan alternative in an assessment of risk to extirpation

Species and outcomes	Alternatives				
	1	2	3	4	5
<i>Arboreal rodent</i>					
Remain	90	90	60	85	85
Extirpated	10	10	40	15	15
<i>Forest landbird</i>					
Remain	95	90	80	90	90
Extirpated	5	10	20	10	10
<i>Small carnivore</i>					
Remain	95	90	60	85	85
Extirpated	5	10	40	15	15
<i>Terrestrial amphibian</i>					
Remain	90	80	50	30	25
Extirpated	10	20	50	70	75

Alternatives vary in the emphasis of land uses or values, ranging from No Action (1) to an emphasis on goods and services (5). Probabilities sum to 100% and estimate whether each wildlife species likely remains well distributed or becomes extirpated across a planning landscape area following implementation of a selected plan alternative for 100 years.

Table 2

Probability (%) that the single most sensitive species in the planning area will become locally extirpated [ $P_{\text{ext}}$  (Most)] and the probability that any (i.e., at least one) wildlife species in the planning area will become locally extirpated [ $P_{\text{ext}}$  (Any)]

Outcomes	Alternatives				
	1	2	3	4	5
$P_{\text{ext}}$ (Most)	10	20	50	70	76
$P_{\text{ext}}$ (Any)	27	42	86	80	84

Both probabilities are calculated from the hypothetical risk values provided in Table 1, which simulate the output of expert opinions used in risk assessment analyses of forest planning alternatives (Shaw, 1999; Quigley et al., 1997).

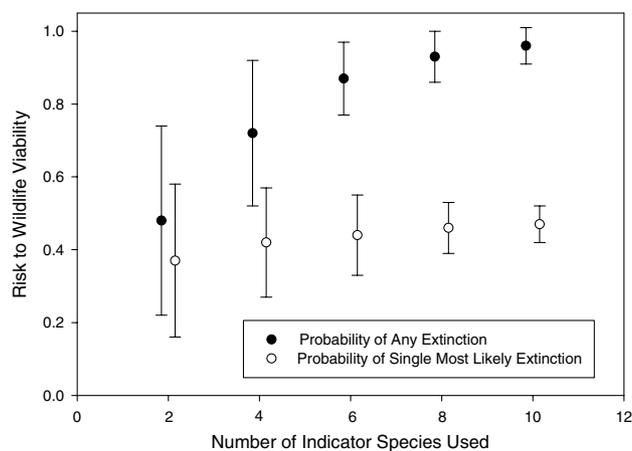


Fig. 1. Results of Monte Carlo simulation contrasting the probability of any extinction with the probability of the single most likely extinction using different numbers of vulnerable indicator species. Each point represents the mean risk ( $\pm 2$  SD) based on 50 replicate sets of species that each had a 0.05–0.45 probability of extinction.

Management Assessment Team, 1993; Quigley et al., 1997; USDA Forest Service, 1997).

The conclusion that using the ‘most vulnerable species’ to choose a preferred alternative may mislead land managers who consider wildlife viability a high priority must seem counterintuitive. This is because on the surface basing a management decision on the projected response of the species with the highest risk of extinction appears to be rooted in a conservative framework. However, a close examination of tenets underlying these approaches reveals that the probability of extinction of ‘any’ of a suite of sensitive species will always be greater than the risk of extinction of a single species. This is because the risk of local extirpation increases with number of extinction prone species in a region (Frankham, 1998; Laurance, 1991). More importantly, the mandate to ensure wildlife viability and maintain biological diversity explicitly charges managers with the responsibility of protecting all indigenous vertebrates in a planning area – not just individual species that appear to be the most vulnerable (Jerry, 1984).

Furthermore, implicit in this approach is an assumption that all species are perfectly correlated in how each responds to a management alternative. Such an assumption is not ecologically tenable. Consider that indigenous vertebrate faunas comprise a diverse ecological assemblage of organisms that include insectivores, carnivores, herbivores, granivores, and omnivores, which often use the environment at different scales and in different ways (Cody and Diamond, 1975; Lancaster, 1996; Wiens et al., 1993). Species of wildlife communities, even those with seemingly similar habitat affinities and life histories, likely do not respond to disturbance uniformly within habitat patches (Mannan et al., 1984; Niemi et al., 1997; Szaro, 1986) or across broader spatial scales (McGarigal and McComb, 1995). Another important consideration is the nature of ‘extrinsic’ forces that influence wildlife populations, as most anthropogenic disturbances are additive and extraneous to ecosystems. Because indigenous communities evolved under unique environmental circumstances, their wildlife populations respond differently to anthropogenic disturbances as compared to natural regimes. Moreover, individual species likely respond differently to the same anthropogenic disturbance (Mannan et al., 1984; Niemi et al., 1997; Szaro, 1986). Indeed, within the same managed landscape species of management concern may require different disturbance regimes and consequently respond divergently to the same management plan alternative (Zollner et al., in press).

Unfortunately, good examples of wildlife communities responding to habitat disturbance are limited. In forest biomes, several investigators demonstrated that members of a community with similar life histories or habitat relations responded inconsistently to forest management prescriptions or land use. This was true of avian guilds (Mannan et al., 1984; Szaro, 1986), arboreal rodent communities (Carey, 2000) and deer mice (*Peromyscus* spp.) populations (Songer et al., 1997; Taylor, 1999) in the Pacific Northwest and woodpecker (Picidae) communities in the Mississippi Alluvial Valley (Smith et al., 1993). Furthermore, species that responded uniformly to stand-level disturbances differed markedly in their response to landscape structure (McGarigal and McComb, 1995). Thus, land management plans developed to reduce extinction risk of the most vulnerable species in communities likely will fail to provide habitat to sustain all indigenous wildlife species across a planning area (Manley et al., 2004).

However, applying the binomial theorem to estimate the probability of ‘any’ extinction is not without limitations. Whereas the practice of identifying the most vulnerable species relied on an implicit assumption of perfect correlation among responses of species at risk, using the binomial to compute a joint probability requires that the responses of species at risk to a management alternative are independent. That is, the

Table 3

Rank order of alternatives for land management plans of national forests in the United States: Northwest Forest Plan (FEMAT), Tongass Land Management Plan (TLMP), and Interior Columbia Basin Ecosystem Management Project (ICBEMP)

Forest Plan/Paradigms	Alternatives								
	1	2	3	4	5	6	7	8	9
FEMAT <sup>a</sup>									
<i>P</i> (Most)	1.5	4.5	1.5	4.5	6.5	6.5	3	–	–
<i>P</i> (Any)	1.5	3	1.5	5	7	6	4	–	–
TLMP <sup>b</sup>									
<i>P</i> (Most)	1	7	3.5	5	3.5	2	8.5	6	8.5
TLMP <sup>b</sup>									
<i>P</i> (Any)	1	7	3	4	2	5	9	6	8
CBEMP <sup>c</sup>									
<i>P</i> (Most)	1	2	3	4	5	6.5	6.5	–	–
<i>P</i> (Any)	1	2	3	5	4	6	7	–	–

Alternatives do not necessarily correspond to numbered plan alternatives of individual assessments, but represent an array of land uses, ranging from No Action (1) to varying emphases on specific goods and services (2–7,9). Rank was based on outcomes of two paradigms of assessing risk of viability of six wildlife species across the planning area: (1) probability of the most sensitive species (Most) in the planning area becoming locally extirpated; and (2) probability that at least one (Any) wildlife species in the planning area becoming locally extirpated. The latter is equivalent to estimating probability of ‘at least one success’, which is computed as the joint probability of marginal probabilities (i.e., extinction probabilities for individual species) according to a binomial distribution. Likelihood scores assigned to the two most severe outcomes for FEMAT, TLMP, and ICBEMP were pooled into a single outcome ‘risk of extirpation’. Species were selected to minimize overlap in life history attributes and ecological scale.

<sup>a</sup> Based on estimates of extinction likelihood for wildlife species evaluated by risk panels (Forest Ecosystem Management Assessment Team, 1993).

<sup>b</sup> Based on estimates of extinction likelihood for wildlife species evaluated by risk panels (Shaw, 1999).

<sup>c</sup> Adapted from estimates of extinction likelihood for wildlife species evaluated by for Bureau of Land Management and Forest Service lands in eastern Oregon and eastern Washington (Quigley et al., 1997).

probability of any species becoming locally extirpated is not directly related to, or influenced by, the response of other species to a management alternative. If the responses of species at risk to a management alternative are not independent, then the probability of any extinction computed according to the binomial theorem overestimates the likelihood of a local extirpation (Walpole and Meyers, 2002).

There are two reasons why the probability of extinction for any of a suite of species may not be truly independent. First, numerous species may respond similarly to an external disturbance (e.g., catastrophic storm) or to activities of the management alternative under consideration. Second, two species may have some ecological dependency (e.g., predation or mutualism) that explicitly links the probability of extinction for one species to that of another. However, in the planning process species at risk are selected to maximize breadth of variation and minimize degree of correlation in response to management alternatives (Shaw, 1999). Furthermore, procedures used to estimate ‘marginal risks’ (i.e., risk of extinction of individual species) typically incorporate information about interactions of species.

In reality, some intermediate degree of direct correlation in response to land management likely occurs for many combinations of species. Quantifying the influence of varying degrees of correlation (negative or positive) among the responses of vulnerable species on the joint probability of extinction is not straightforward (Walpole

and Meyers, 2002) and beyond the scope of this paper. Our expectation is that the unique life history or ecological attributes of species (e.g., habitat or diet specialization) that render them more vulnerable to extinction also reduce opportunities for correlated responses to land use. Nevertheless, whether the probability of extinction of single species is determined by PVA (Akçaya, 1992) or from expert panels (Shaw, 1999), these estimates incorporate impacts to critical resources, (e.g., key prey species) or facultative ecological relationships (e.g., primary cavity nesters) in their overall assessment of a management alternative on the viability of species at risk. In those circumstances, concerns about violating assumptions of independence because of strong interspecific ecological relationships diminish substantially.

Selecting the binomial theorem as an appropriate model when considering risk to viability creates an additional practical dilemma. That is, the probability of at least one extinction necessarily increases as the number of taxa under consideration increases. From a theoretical perspective, this is appropriate because it is consistent with the underlying premise that the probability of extinction becomes greater as number of sensitive taxa in a planning area increases, regardless of management activities. Furthermore, this premise applies to the current paradigm of basing decisions on the response of the single-most sensitive species at risk (Fig. 1). Consider that the most sensitive species selected from larger pools

of potential species at risk will on average face greater risks to viability due to the same sampling effect.

The potential magnitude of disparity between characterizing risk of extinction by focusing on the most sensitive species versus simultaneous consideration of multiple sensitive taxa is substantial and should be sensitive to the number of species at risk used in an analysis. The results of our Monte Carlo simulation (Fig. 1) demonstrate both the influence of the number of species at risk included in an analysis (described above) and the disparity in performance of these two approaches. Recall that the maximum risk of any single species in our simulated scenario was 0.45. Fig. 1 demonstrates how this upper bound on the risk of the single most likely extinction causes the two indices to provide very different estimates of extinction risk following implementation of a management plan alternative. It also demonstrates that as the number of species at risk in an analysis increase, the probability of any extinction asymptotes towards one, and the probability of the single-most likely extinction asymptotes towards the risk of extinction faced by the most vulnerable species.

These results support our contention that species at risk should be selected carefully with stringent guidelines regarding the number of species selected and the ecological relationships among species. Moreover, calculating the probability of ‘any’ extinction provides a more conservative measure of the level of threat from land management to indigenous wildlife across a planning area than choosing the most sensitive species. The take home message for planning efforts is that a more realistic appraisal of level of threat may be achieved by including some consideration of the number of sensitive taxa across a planning area when developing lists of species at risk. Furthermore, without a judicious process to select sensitive taxa, assessing risk to viability within the proposed framework can easily become impractical or ineffectual.

#### 4. Conclusions

The challenges of land management planning of large areas make it essential for managers to recognize the diversity of responses that occurs among wildlife species and acknowledge the implications for risk to viability. There are many tools and approaches that are invaluable in addressing this objective. Many of these approaches rely upon the response of a single species to reflect the impact of forest management on an ecological guild (Verner, 1984), or even an entire ecosystem (Shaw, 1999). We argue and illustrate with a hypothetical example and a simple Monte Carlo simulation that the practice of using the most vulnerable species will frequently underestimate the risk of losing species from indigenous wildlife communities. Furthermore, we propose that an

estimate of the risk of losing ‘any’ species based on a binomial theorem will better represent the risk to wildlife viability in land management planning. The implications of accomplishing these more realistic assessments of threat to extinction from land use are numerous and far-reaching, not the least of which is the influence it might have on the selection of the preferred land management planning alternative. Moreover, we believe that acknowledging a greater extinction risk across the planning area will inspire a more judicious process of crafting land management alternatives. Indeed, developing an appropriate conceptual basis for developing land-use options and evaluating impacts of land management on biological communities is fundamental to achieving sustainable use of natural resources.

The principles developed in this paper are rudimentary and we do not presume to suggest our approach embodies the most appropriate conceptual framework or that it should be used to the exclusion of other relevant tools and approaches. Rather, we believe that the principles we outline in this paper are linked to fundamental tenets of evolutionary ecology and conservation biology (i.e., extinction risk increases with number of sensitive taxa) that rarely are explicitly considered in effects analyses. Furthermore, we believe that incorporating these principles into land management planning will supplement and enhance existing approaches by focusing planners on assumptions that can substantially influence risk assessments of wildlife viability. Moreover, these principles may be applied to land management planning of biomes throughout the world. Naturally, the land management objectives of an area will determine the relative importance of maintaining different elements of an ecological community. Still, we reiterate that regardless of how one uses the results of effects analyses in decision-making, the approach selected to estimate risk to wildlife viability likely will profoundly influence the outcome. Finally, we emphasize that no matter what model is used to assess land management scenarios the inference derived from such analyses should be based on comparisons among alternatives (including a ‘No Action’ scenario) with a consistent set of assumptions (Possingham et al., 1993, 2002), rather than on an absolute prediction of a future state following implementation of a selected plan. This emphasis on drawing relative inference from a ranking of alternatives is important to dissuade erroneous impressions that sufficient data exist to accurately predict viability, or that any land management alternative will ensure the persistence of wildlife indefinitely.

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